THE IMPORTANCE OF SESMIC INSTRUMENTS IN DAM MONITORING

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ABSTRACT: As earthquake ground shaking affects the dam body and appurtenant structures and all hydro mechanical and electromechanical components etc. of a dam project at the same time, the earthquake load case is probably the most challenging one for hydraulic engineers. Thus all these elements have to be able to resist some degree of earthquake action. A large number of high dams in the world and in our country are located within high seismicity zones, which were affected by string earthquakes in the past. Seismic monitoring of the dams and the results which are obtained from them has become an increasing need in the earthquake engineering and has considerable contribution to the overall activities for seismic risk reduction. The main objective in seismic monitoring of dams are to facilitate response studies that lead to improved understanding of the dynamic behaviour and potential for damage to structures under seismic loading. Presented in this paper shall be some ideas and results from the seismic monitoring of the dams.

KEY WORDS: *Earthquake, dam safety, existing dams, concrete dams, embankment dams, emergency planning, seismic analysis of dams, seismic design*

INTRODUCTION

Dams are important structures, which have contributed significantly to the economic development of many countries. The great majority of existing dams – mainly smaller ones -were built for irrigation and water supply. Most large dam projects are multipurpose projects for energy production, flood control, navigation, water supply and irrigation, recreation, aquaculture etc. Any failure of dams not only causes loss of life and damage to property, but also affects economy of the country. During the 2001 Bhuj earthquake in India about 245 embankment dams – most of them small dams used for irrigation and water supply – were damaged. Fortunately, the reservoirs were almost empty at the time of the earthquake and thus further damage could be prevented. Little experience exists about the seismic performance of modern RCC and concrete face rock fill dams, which are being built in increasing number today. It is, as such, imperative that safety of dams is ensured in all its aspects. Existing dams constructed in earlier times, not conforming to current design practices, also merits equal attention with regard to safety aspects through strengthening measures. There is an increasing awareness in recent times not only among the engineers but also among the general public, about the safety of dams. This has made it essential to gather information to monitor performance and safety of dams. Effective instrumentation can help to monitor the safety of dam and its proper maintenance and up-keep. Therefore, it is necessary that concerned officers and staff do have proper exposure to the work of instrumentation, maintenance and relevant records/data and their analysis. Also in our country, the variety of concepts and technologies involved in instrumentation of dams are little known. As large storage dams may have very large damage potentials, they must also be able to withstand the effects of very strong earthquakes until now no people have died from the failure or damage of a large water storage dam due to earthquake. Earthquakes have always been a significant aspect of the design and safety of dams. In many parts of the world the earthquake safety of existing dams is reassessed based on recommendations and guidelines documented in bulletins of the international-commission-on-large-dams (ICOLD).

EFFECTS OF THE EARTHQUAKE ON DAM STRUCTURE

In the case of dams the main load is the water load, which in the case of concrete dams with a vertical upstream face acts in the horizontal direction. In the case of embankment dams the water load acts normal to the impervious core or the upstream facing. Earthquake damage of buildings and bridges is mainly due to the horizontal earthquake component. Concrete and embankment dams are much better suited to carry horizontal loads than buildings and bridges. In order to prevent the uncontrolled rapid release of water from the reservoir of a storage dam during a strong earthquake, the dam must be able to withstand the strong ground shaking from even an extreme earthquake, which is referred to as the Safety Evaluation Earthquake (SEE) or the Maximum Credible Earthquake (MCE). Large storage dams are generally considered safe if they can survive an event with a return period of 10,000 years, i.e. having a one percent chance of being exceeded in 100 years. It is very difficult to predict what can happen during such a rare event as very few earthquakes of this size have actually affected dams.

MULTI-HAZARDIOUS EFFECTS OF THE EARTHQUAKES IN THE CASE OF A STORAGE DAM:

• Ground shaking causes vibrations and structural distortions in dams, appurtenant structures and equipment, and their foundations;

• Fault movements in the dam foundation or discontinuities in dam foundation near major faults can be activated, causing structural distortions;

• Fault displacement in the reservoir bottom may cause water waves in the reservoir or loss of freeboard;

• Rock falls and landslides may cause damage to gates, spillway piers (cracks), retaining walls (overturning), surface powerhouses (cracking and puncturing and distortions), electro-mechanical equipment, penstocks, masts of transmission lines, etc.

• Mass movements into the reservoir may cause impulse waves in the reservoir;

• Mass movements blocking rivers and forming landslide dams and lakes whose failure may lead to overtopping of run-of-river power plants or the inundation of powerhouses with equipment, and damage downstream;

• Ground movements and settlements due to liquefaction, densification of soil and rock fill, causing distortions in dams;

• Abutment movements causing sliding of and distortions in the dam.

Therefore, in the earthquake design of dams all seismic hazard aspects must be considered and depend on the local conditions of a storage dam project..

SEISMIC DEFORMATIONS IN CONCRETE DAMS

The few observations of earthquake damage in concrete gravity dams show that ground shaking results in formation of cracks in the highly stressed central crest region along some weak planes, such as horizontal lift surfaces and grouted vertical contraction joints (Fig. 1). Once a concrete block gets separated from the rest of the dam by such cracks, it can experience substantial inelastic (nonlinear) displacements in the form of rocking and sliding without actually leading to a dam failure.. However, based on linear-elastic dynamic analyses, it is obvious that a strong earthquake induces tensile stresses that exceed the dynamic tensile strength of mass concrete and thus joint opening and/or cracking can be expected.

Fig. 1: Horizontal crack at lift joints(left: crack at upstream face; right: crack in web of buttress at downstream face of the dam)

SEISMIC DEFORMATIONS OF EMBANKMENT DAMS

The seismic safety of embankment dams is assessed by investigating the following:

• Permanent deformations experienced during and after an earthquake (e.g. loss of freeboard);

• Stability of slopes during and after the earthquake, and dynamic slope movements;

• Build-up of excess pore water pressures in embankment and foundation materials (soil liquefaction);

• damage to filter, drainage and transition layers;

• Damage to waterproofing elements in dam and foundation (core, upstream concrete or asphalt membranes, geotextiles, grout curtain, diaphragm walls in foundation, etc.)

• Vulnerability of dam to internal erosion after formation of cracks and limited sliding movements of embankment slopes, or formation of loose material zones due to high shear, etc.

For large embankment dams, the expected seismic deformations must be determined. The calculations of the permanent settlement of large rockfill or concrete-face rockfill (CFR) dams are rather approximate, as dynamic soil tests are usually carried out with aggregate sizes of less than 5 cm. This is a problem for dams, where the coarse rock aggregates, have not been properly compacted at the time of construction. Poorly compacted rockfill may settle significantly during strong ground shaking but may still withstand strong earthquakes. Transverse cracking as a result of deformations is an important aspect. Cracks could lead to failure of an embankment dams when the dam does not have filter, drain and transition zones, or filter, drain and transition zones do not extend above the reservoir water surface, or modern filter criteria were not used

PURPOSE OF SEISMIC MONITORING ON DAMS

- precise location of earthquake epicenters and their depth
- Definition of main earthquake parameters: magnitude, frequency characteristics and some indications of focal mechanisms;
- prediction of the mode of occurrence of future earthquakes;
- provision of data on the dynamic behavior of the dam body for the purpose of objective evaluation of its functioning immediately after the occurred earthquake,
- Verification of design parameters by the actual behavior of the dam body under an earthquake.

To provide the various information that are of different nature, it is necessary to investigate and monitor the dam site by means of various seismic instruments and it is desirable to installing seismic instruments on and near major dams. Various types of instruments are required: (1) Strong-motion accelerographs for recording potentially destructive ground shaking and resulting dam vibrations; and (2) sensitive seismographs for determining the local seismicity. A minimum of two strong-motion accelerographs should be installed on the dam and a minimum of two should be installed in the immediate vicinity of the dam. Each accelerograph should record three components of motion, should have a natural frequency of approx. 20 Hz, a recording speed of approx 1 cm/s. The sensitive seismographs are intended to record the local seismicity in the vicinity of the dam site before construction, and to detect any changes in seismicity during reservoir filling. A minimum of three seismographs is recommended for installation in the vicinity of the dam site. A vertical-component seismometer (1 Hz - 5 Hz) with visual recorder and approx l0,000 magnification at 1 Hz is recommended. (3) seismic data analysis system (4) Magnetic tape play-back system (5) Digital time marking system (6) Digital event recorder.

The instruments are suitable to record the earthquake detail to record the earthquake upto magnitude 8.0 on ritcher scale. Also the micro-earthquake may contain frequencies upto hundreds of Hertz(Hz) while an earthquake recorded in a seismic net may contain frequencies between 1 and 20 Hz. So that it is very difficult to achieve such a dynamic range in a single recording system with equal response to all the frequencies.

SEISMIC DESIGN CRITERIA FOR DAM PROJECTS

Seismic Design Criteria for Dam and Safety-relevant Components For the seismic design of dams, abutments and safety-relevant components (spillway gates, bottom outlets, etc.)the following types of design earthquakes are used in accordance with ICOLD Bulletin 72 (1989):

(i)Operating Basis Earthquake (OBE): The OBE design is used to limit the earthquake damage to a dam project and, therefore, is mainly a concern of the dam owner. Accordingly, there are no fixed criteria for the OBE although ICOLD has proposed an average return period of ca. 145 years (50% probability of exceedance in 100 years). Sometimes return periods of 200 or 500 years are used. The dam shall remain operable after the OBE and only minor easily repairable damage is accepted.

ii) Maximum Credible Earthquake (MCE), Maximum Design Earthquake (MDE)or Safety Evaluation Earthquake (SEE): Strictly speaking, the MCE is a deterministic event, and is the largest reasonably conceivable earthquake that appears possible along a recognized fault or within a geographically defined tectonic province, under the presently known or presumed tectonic framework. But in practice, due to the problems involved in estimating of the corresponding ground motion, the MCE is usually defined statistically with a typical return period of 10,000 years for countries of low to moderate seismicity. Thus, the terms MDE or SEE are used as substitutes for the MCE. The stability of the dam must be ensured under the worst possible ground motions at the dam site and no uncontrolled release of water from the reservoir shall take place, although significant structural damage is accepted. In the case of significant earthquake damage, the reservoir may have to be lowered. Historically, the performance criteria for dams and other structures have evolved from the observation of damage and/or experimental investigations. The performance criteria for dams during the OBE and MCE/SEE are of very general nature and have to be considered on a case-by-case basis. Because bottom outlets and spillway gates have to be operable after the SEE ground motion, the performance criteria for these safety-relevant elements are stricter than for the dam body, which may be cracked or has undergone different types of deformations.

SAFETY PHILOSOPHY FOR DAM PROJECTS

The main safety concern is the failure of a dam and the uncontrolled release of the reservoir water with flood consequences (loss of life, economical damage, environmental damage etc.), which will usually exceed the economical damage to the dam. Therefore, for the seismic risk assessment of a dam, full reservoir is the critical situation .Basically; the seismic safety of a dam depends on the following factors:

1. Structural Safety: strength to resist seismic forces without damage; capability to absorb high seismic forces by inelastic deformations (opening of joints and cracks in concrete dams; movements of joints in the foundation rock; inelastic deformation characteristics of embankment materials); stability (sliding and overturning stability), design of dam according to state-of-practice, etc.

2. Safety Monitoring: strong motion instrumentation of dam and foundation; visual observations and inspection after an earthquake; data analysis and interpretation; post-earthquake safety assessment etc.

3. Operational Safety: Rule curves and operational guidelines for post-earthquake phase; experienced and qualified dam maintenance staff, etc.

4. Emergency Planning: water alarm; flood mapping and evacuation plans; safe access to dam and reservoir after a strong earthquake; lowering of reservoir; engineering back-up, etc .In general, dams, which can resist the strong ground shaking of the MCE, will perform well under other types of actions. It is obvious from the above list that structural safety and earthquake resistant design of a dam is only one element, but a very important one, in the overall safety philosophy of large dams.

CONCLUSIONS

The technology for designing and building dams and appurtenant structures that can safely resist the effects of strong ground shaking is available. Dam construction has moved from the West to the less developed countries and the existing dams are ageing not only physically but also the design criteria and design concepts are getting old. This is particularly true for seismic action where a lot of developments have taken place since the 1971 San Fernando earthquake, a milestone in modern earthquake engineering.

Dams are not inherently safe against earthquakes. In regions of low to moderate seismicity where strong earthquakes occur very rarely, it is sometimes believed (i) that too much emphasis is put on the seismic hazard and earthquake safety of dams, and (ii) that dams designed for a seismic coefficient of 0.1 are sufficiently safe against earthquakes as none of them has failed up to now. Such arguments are not correct.

For the earthquake safety evaluation the same criteria (dam must withstand the MCE ground motion) as for the hydrological safety (PMF must be released safely) have to be considered. As most dams built prior when ICOLD has published its seismic design criteria of dams, have not been checked for the behavior and safety for the maximum credible ground motion at the dam site, the earthquake safety of these dams is not known and based on the comprehensive safety checks carried out in California it must be assumed that quite a number of them do not satisfy today's seismic safety criteria. Therefore, owners of older dams shall start with the seismic safety checks of their dams.

They shall also realize (i) that the earthquake load case has evolved as the critical load case for most large dams even in regions of low to moderate seismicity and (ii) that due to changes in the seismic design criteria and the design concepts it may be necessary to perform several seismic safety checks during the long economical life of a large dam. This is also true for other infrastructure projects and buildings. Finally we have to realize that our knowledge on the behaviour of large dams during very strong ground shaking s still very limited and that each destructive earthquake affecting dam may reveal some new features, which upto now may have been ignored (Wieland and Brenner,2008).

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